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STEPS TOWARDS TERRAIN KNOWLEDGE ACQUISITION

Third Interim Report

by

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Steps towards terrain knowledge acquisition

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In all earlier efforts in constructing prototype expert terrain-related systems, knowledge related to the physiographic region of a site was not explicitly represented and used. In this research we have identified, named, described and organized detailed, "book-level" knowledge pertaining to physiographic regions (provinces and sections). We have developed an object-oriented model for the structural representation of the relevant domain knowledge. We have also developed a rule-base for representing the strategic knowledge needed for inferring a physiographic region from its own indicators. The presented case study concerns typical terrain of the Basin and Range Province of Southwest USA. The knowledge representation encompasses the typical physiographic sections of the Basin and Range province (Great Basin and Sonoran Desert). This conceptual scheme will lead to the Terrain Analysis eXpert (TAX-4) system. Formalizing and implementing these knowledge-based representations will result in an expert system for physiographic region identification so that the user will be guided to establish tentative hypotheses about the type of physiographic regions based on observed evidences of their indicators.

Landform interpretation, physiographic regions, knowledge-base, terrain analysis, expert systems

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Introduction: Knowledge-based Landform Interpretation

For the past ten years, scientists working toward knowledge-based landform interpretation have developed various approaches and have implemented expert system prototypes for terrain analysis (Leighty 1973, Leighty 1979, Rinker and Corl (1984), Edwards 1988, Argialas 1988, Argialas and Narasimhan 1988a and 1988b, Argialas 1989, Narasimhan and Argialas 1989, Mintzer 1988). The approach by Argialas and his associates (TAX 1, 2, 3) has used different methods of knowledge representation such as rules, frames, Bayesian reasoning under uncertainty, and fuzzy descriptors to address terrain knowledge-representation through the landform-pattern element approach and to construct prototype expert-systems for inferring the landform of a site from user observations of pattern elements.

The identification and conceptualization stages of TAX 1, 2, 3 (Argialas 1988, Argialas and Narasimhan 1988a and 1988b, Argialas 1989, Argialas 1996) was characterized as following:

- The class of problems the expert system was expected to solve was the inference of the landform type of a site, assuming that one landform type was present on the site. The user was asked first to choose the physiographic region of the site, and then he/she was guided to provide the pattern elements of the site.
- The conceptual scheme for the recognition of the landforms was the landform pattern-element approach. The hypotheses were the landforms and the evidences or data used for inference were the pattern-elements of a site. The association between physiographic sections and their expected landform types were described with the use of probabilities expressing the occurrence of each landform in the corresponding physiographic section.
- Six landform types were chosen to focus the knowledge-representation process, the humid and arid forms of sandstone, shale and limestone. Six to ten pattern elements were collected for each landform. The landforms being considered for the knowledge-representation process are those that are common to the Cumberland Plateau section, e.g., sandstone, shale, limestone. This domain knowledge was composed of facts collected from (1) books (Way 1978, Lillesand and Kiefer 1979), (2) reports (Mintzer and Messmore 1984), (3) the experience of the authors, and (4) an interview with an expert terrain analyst. Humans use a lot more evidences and reasoning which were not taking into account.

METHODOLOGY

Terrain knowledge acquisition involves development of the following five interdependent and overlapping typical tasks for building the Terrain Analysis eXpert system prototypes: (1) Identification, (2) Conceptualization and representation, (3) Formalization, (4) Implementation, and (5) Testing and evaluation. In the following we develop the first two for the Terrain Analysis Expert (TAX-4).

Knowledge Identification

The class of problems the TAX-4 expert system was expected to solve has included as its major addition the physiographic context reasoning in addition to our previous scheme. It is evident that the expert in deciding the landform of a site is studying first, among other things, the physiography of a region and performs a kind of physiographic analysis and reasoning so that to create reasonable hypotheses of the possible landforms of the site. On the other hand if the expert has already identified a landform, he is in a position to create physiographic region hypotheses and consequently to be guided to interpret additional landforms. We call this type of reasoning physiographic context reasoning. Physiographic context reasoning is an informal task at present since it is not described explicitly in a formal manner in books and guides. In the following we develop a formal conceptual framework for the representation of physiographic context reasoning within an expert system. Emphasis is placed in the definition of the subproblems and subtasks trough domain-dependent concepts, hypotheses and data.

To practically demonstrate the developed conceptual scheme we will give examples reflecting the physiographic context of the Basin and Range Province and its pertinent piedmont plain and basin floor landforms (alluvial fans, pediments, bahadas, playas, valley fills). The relevant knowledge was collected from physiographic and geomorphologic books and reports and mainly from Fenneman (1931, 1938), Lobeck (1932), Hammond (1954), Lueder (1959), Hunt (1973, 1975), Peterson (1981), Pandey (1987). In the following we briefly describe the relevant physiographic and geomorphologic knowledge that was identified and used for the presented conceptual scheme.

Geologists and geographers have subdivided the United States into areas called physiographic provinces, each of which has characteristic landforms. In the conterminous USA more than 80 such subdivisions are recognized, but for simplification they have been grouped together into 25 major provinces. This classification of landforms has been further simplified by grouping the provinces into six large regions. The six regions are (1) the Central Stable Region, (2) the Appalachian Highland

Region, (3) the Ozark Region, (4) the Cordillera Mountain Region, (5) the Great Plains Region, and (6) the Atlantic Coastal Plain Region.

The Cordillera Mountain Region is a wide mountainous belt that stretches from Central America northward to Alaska composed of a series of ranges. It occupies the Western third of the United States. One of its provinces, the Basin and Range Province is centered principally on the State of Nevada but extending across the Southern parts of Arizona and New Mexico, located west & south of Colorado Plateaus. It is a large area, one tenth of USA, occupied mostly by wide desert plains, generally almost level, interrupted by great, largely dissected, north trending, roughly parallel mountain ranges formed by a series of tilted fault blocks (Figure 1). The typical block mountain has an escarpment on the faulted side and a long, comparatively gentle slope away from the fault. The differences in slope on the two sides are significant. Climatically is characterized by want of sufficient runoff to reach to sea or to forward its load of detritus. The Province of Basin and Range is further subdivided to five sections of unequal size and of different erosion cycles such as the Great Basin (youthful erosion stage) and Sonoran Desert (of maturity erosion stage). (Fenneman 1931 and 1938). We describe the two of them below (Figure 1).

- Great Basin. A large part of the Basin and Range province, in its northern half and mainly in Arizona & New Mexico, is known as the Great Basin section because its drainage waters do not reach the sea but evaporate in saline lakes on the plains between the mountain ranges. Such basins are by no means universal. Much of the area has slopes on which water might run directly to the sea but it is too arid to supply continuous flow. Considerable areas have no run-off at all. The space taken by the mountains is about the half of the total.
- Sonoran Desert. It is south of and much lower in altitude from Great Basin. Mountain ranges are smaller and perhaps older, occupying perhaps the 1/5 of the space. Moreover large areas are without concave basins of internal drainage and the section belongs to the maturity erosion cycle

Knowledge Conceptualization and Representation

Knowledge conceptualization and representation aim at uncovering the key concepts of the domain and the relationships between them and at conceiving a formal description of knowledge in terms of the primitive concepts and conceptual relations. Based on the earlier identified physiographic components and features, we now present a conceptual framework for the representation of both structural and strategic knowledge (Figure 2). For the structural representation of physiographic knowledge we assume an object-oriented representation structure that uses frames as classes, subclasses, objects, subobjects, and slot frames as properties. For the strategic knowledge representation we assume a rule based inference engine.

Structural Knowledge

First, we identified the need to name and describe by their properties the classes of our domain:
- physiographic regions as a whole,
- the Basin and Range concept,
- the Basin and Range youthful stage,
- the Basin and Range maturity erosion stage, and
- additional physiographic regions such as the Coastal Plain, etc.

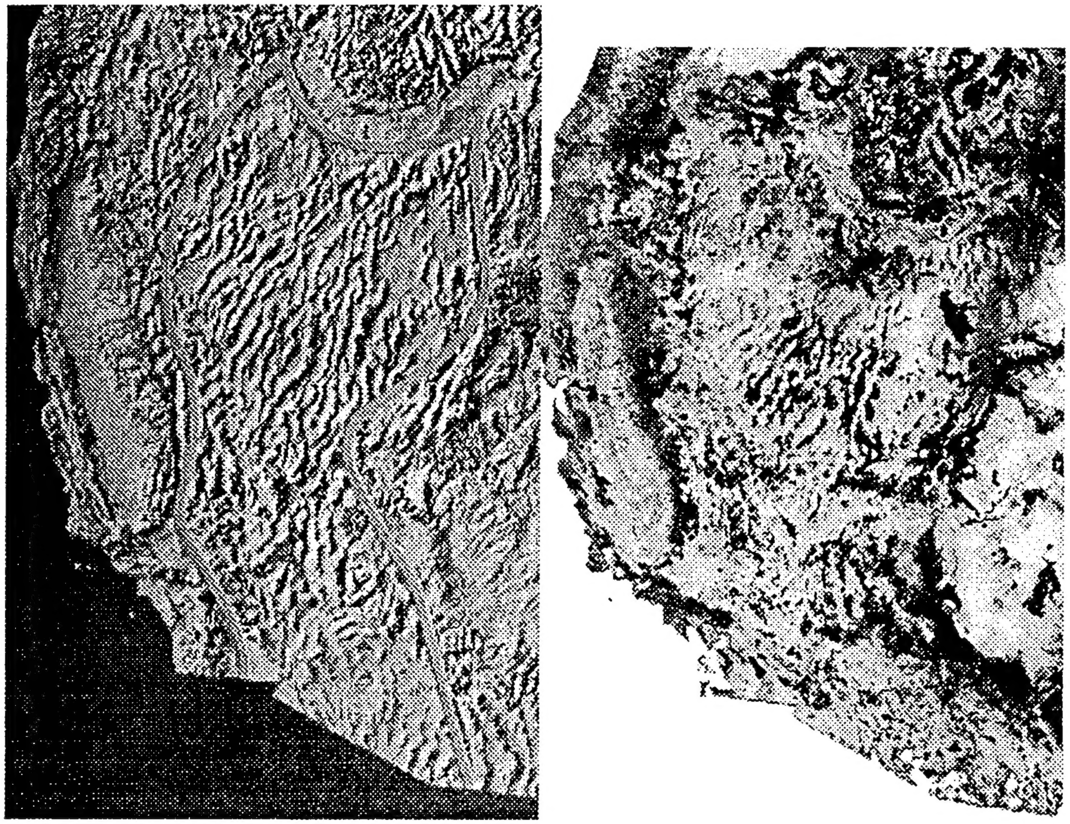

Figure 1. Basin and Range province and its sections. From upper left clockwise (a) a radar image of the west USA with the province outlined (Thompson and Turk 1993), (b) Landsat MSS computer enhanced mosaic of west USA (Short and Blair 1986), (c) the location of Great Basin and Sonoran Desert in West USA (Helms 1986).

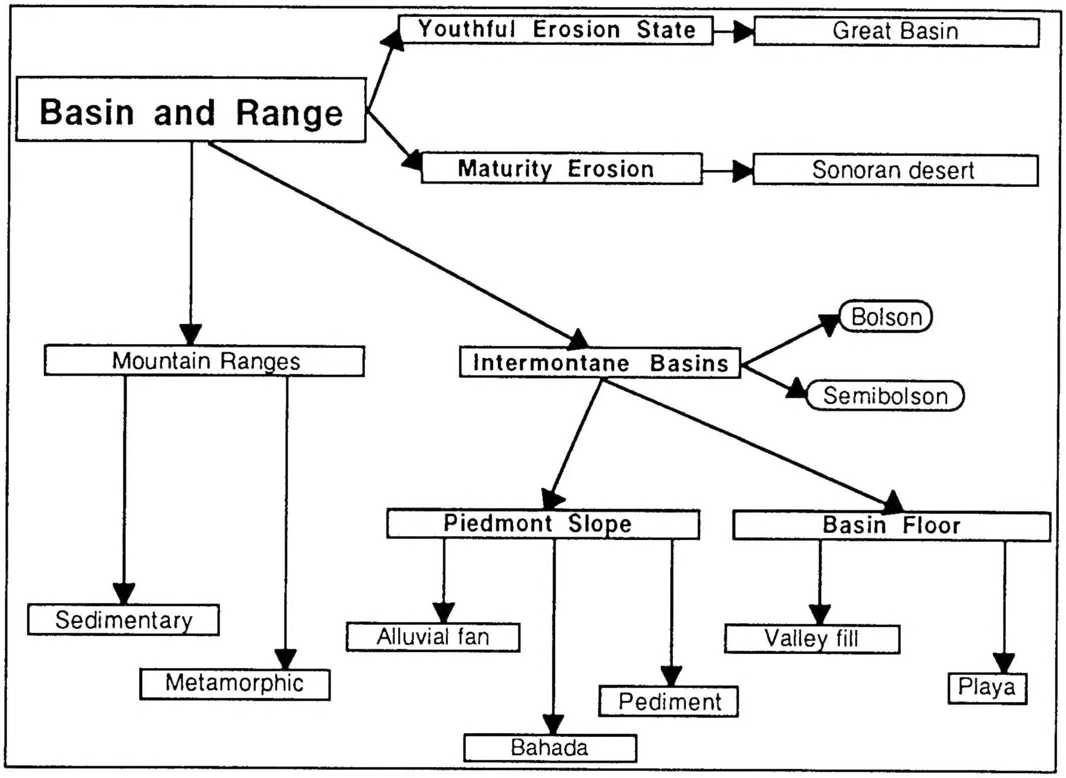

Figure 2. The major entities of the Basin and Range Concept.

The term physiographic region, in our conceptual scheme, encompasses both the physiographic provinces and the sections according to the traditional USA physiographic approach (Fenneman 1931 and 1938).

Second, we organized physiographic classes into *class-subclass hierarchies*. Classes included sub-classes so that additional levels of detail were described only in the subclasses. Describing classes through subclasses gave access to a hierarchical representation of concepts and objects. Third, we defined an object-subobject or whole-part hierarchy.

In our study of the USA physiographic provinces and sections, we have recognized that behind each particular USA province or section was hidden a physiographic concept defined by specific geomorphologic criteria. Furthermore, in our search for a scheme to represent all the basin and range type of terrain in the world, we forced to define the Basin and Range concept-class and to let each of these terrain units to be members of this class. Thus, since a class, in our object-oriented design framework, acts as a template that defines the properties of its members, we exercised care so that to define for each physiographic province (e.g., the Basin and Range USA) an equivalent concept-class so that each specific instance of the concept-class, e.g., the Basin and Range (USA), to be an object belonging to that class. The same design was followed for the sections of the Basin and Range, e.g., Great Basin and Sonoran Desert. We have recognized that these sections, actually correspond to different erosion stages: the first is in the youthful erosion stage and the second is in the maturity erosion stage. Therefore we have developed the corresponding classes of the youthful and maturity stages of the Basin and Range concept-class. These classes and subclasses are shown as little circles on the plain of physiographic regions of Figure 3.

Forth, we defined *class members or instances*. While classes are useful in representing a concept as a whole, it is necessary to define individual (static or dynamic) object instances of each class or subclass so that to use them for symbols as we interpret features of each class on an image. The members of a class are its objects and are typically referred to as "instances of a class." They express a class-member or class-instance relationship. Some of these instances are dynamic objects generated during our reasoning and inferencing, e.g., they do not exist beforehand. Thus we consider physiographic region instances such as PH1, PH2, PH3, etc. belonging to each physiographic class-concept.

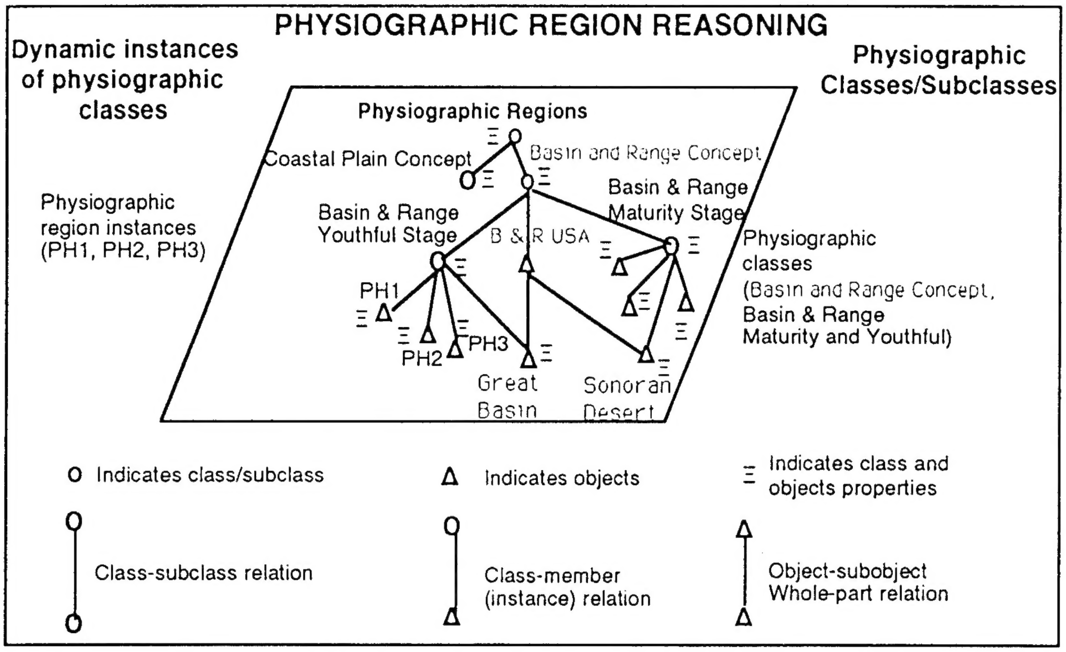

Figure 3. An object-oriented graphical representation of the conceptual scheme of physiographic-region reasoning in TAX-4.

Fifth, each class was defined by a set of properties which define the class. These properties are shown with the symbol Ξ in Figure 3. Objects and subclasses can obtain their properties dynamically from a particular class through a mechanism called inheritance. Thus through the class-subclass or class-instance hierarchy these properties are inherited down each hierarchy so that to be shared by all the members and instances of each class. The properties of the physiographic regions are defined so that to reflect the distinguishing characteristics of each class and they are termed *physiographic indicators.*

The synthesis of physiographic indicators was done in a bottom-up approach by a study of physiographic books and reports (Fenneman 1931 and 1938). The identification of the properties was done according to the geomorphologic process and the topographic descriptions of the various geomorphologic and topographic features mentioned in these books. As an example, in the chapter of Basin and Range, in the Sonoran Desert Section under the title of "Basins" we underlined the following statements in a paragraph:

> While the area occupied by mountains is smaller in this section than in the Great Basin, the extent of rock platforms, bare of detritus or only thinly covered is correspondingly large. It is estimated that 1/5 is covered by mountains, 2/5 by rock platforms and the remaining 2/5 by deposits of detritus.

and we have designed the following property for the Sonoran Desert Section class:
proportion_of_Mountain_Ranges_versus_Piedmont_Plains_versus_Basins= 20% / 40% / 40%

Strategic (inferential) Knowledge

Now, having defined the classes, subclasses, objects, component objects, and instances of physiographic regions, we can use them to describe the *physiographic region reasoning* (Figure 3).

Rules were developed which pertain to the interpretation of physiographic regions (provinces and sections) from their physiographic indicators. It should be emphasized that the approach developed aims at inferring the geomorphologic concept hidden behind a province or a section so that the methodology is applicable to all basin and range landscapes of the world, not only the USA Basin and Range province. Thus the present methodology is expected to be easily extended to all relevant physiographic regions. Follows one of the simple rules that infers the Basin and Range province.

Since it may be difficult for all users to answer the queries of complex physiographic rules, we have designed multiple rules for each physiographic region, each having a variable number of premises. Thus the physiographic region rules were ranked according to their difficulty and different weights were given to each rule to reflect the certainty of the outcome hypothesis for a given physiographic region.

Basin-and_Range_partial_rule_1

IF

frequency_of_mountain_ranges	is "high"
presence_of_desert_basins	is "high"
shape_of_a_mountain_range	is "assymetric"
relative_spatial_position_of_mountain_ranges	is "rather straight"
overall_direction_of_mountain_ranges	is "roughly parallel"
overall_description	is "basin ranges intervening desert planes"

Then Basin_and_Range is true with certainty=medium

Basin-and_Range_partial_rule_2

IF

frequency_of_mountain_ranges and	"high"
presence_of_desert_basins and	"high"
overall_description	"basin ranges intervening desert planes"

Then HYPOTHESIS Basin_and_Range is true with certainty=low

Besides the rules for inferring a physiographic concept at the level of a province, rules were developed, following a method of conceptual refinement, which refined the concept of the province-concept to that of a physiographic section-concept of that province. In the case of the Basin and Range concept, the refinement rules inferred the concept of a youthful or mature erosion stage which correspond to the USA Great Basin and Sonoran Desert sections correspondingly. One of the rules that infers the Maturity Erosion Stage concept follows.

Rule for the Basin and Range-Maturity_Erosion_Stage

IF

relative_relief_of_region	"low"
relaltive_size_of_mountains	"small"
slope_change_at_piedmont_angle	"not abrupt"
shape_of_basins	"rather plain than concave"
overall_hypsometric_distribution_within_the_section	"more than 1/2 of the surface is below 2000 ft"
proportion_of_Mountain_Ranges_versus_Piedmont_Plains_versus_Basins	"20% : 40% : 40%"
amount_of_observed_tectonic_evidences_in_mountain_ranges	"low (the minority has a fault origin)"
degree_of_basin_integration	"high"
stage_of_erosion_cycle	"maturity (advanced,late)"
frequency_of_bolsons	"low (less prelevant)"
frequency_of_semi_bolsons	"high (more prelevant)"
degree_of_integration_of_drainage_pattern	"high"
outlet_of_the_drainage_network	"usually to another drainage basin"

Then Basin_and_Range_Maturity_Stage is true and certainty= medium

CONCLUSIONS AND PROSPECT

We have worked towards the identification, conceptualization, and representation of physiographic knowledge, relying mostly on book-level knowledge, not only because of the lack of an expert interpreter, but also because the first step in knowledge acquisition requires the formulation of a conceptual framework of shallow and deep knowledge, which usually is found in books and reports. Our present-level knowledge falls into the category of "zeroth to first order approximation of physiographic knowledge". We have made an extra effort in capturing a number of "intermediate-level concepts" which are perhaps the most important tools available for organizing knowledge bases, both conceptually and computationally. Going too much to the books and reports may have lead us to the incorporation of knowledge that is either not a part of practical reasoning or that has exceptions that the expert has had to discover and work around. It is therefore necessary, in future efforts, to acquire the "second to third order level of knowledge" from experts. Our feeling is that the expert's knowledge will be more of the heuristic type, e.g., exceptions and corrections of the "zeroth order of knowledge".

The identification of terrain-related objects, their organization. and their relations is the hardest part of conceptualization. Identification of the conceptual structure involves both discovery and invention of the key abstractions and mechanisms that form the vocabulary of our terrain analysis problem and it will come with very hard work.

REFERENCES

Argialas, D., 1996. Towards Structured Knowledge Models. Zeitschrift für Geomorphologie (accepted, in print).

Argialas, D. 1988. Methodologies of Expert Systems for Terrain Analysis Problem Solving. Technical Paper, Annual Convention of American Society for Photogrammetry and Remote Sensing, Vol. 3, σελ. 76-85, St. Louis, Missouri, March 13-19, 1988.

Argialas, D. 1989. A Frame-based Approach to Modeling Terrain Analysis Knowledge. Technical Paper, Annual Convention of American Society for Photogrammetry and Remote Sensing, Vol. 3, pp. 311-319, April 2-7, 1989, Baltimore, Maryland.

Argialas, D., and C. Harlow, 1990. Computational Image Interpretation Models: An Overview and a Perspective, Photogrammetric Engineering and Remote Sensing, Vol. 56, No 6, June, pp. 871-886.

Argialas, D., & O. Mintzer 1992. The potential of hypermedia to photointerpretation education and training. - In: L. Fritz and J. Lucas (eds.): International Archives of Photogrammetry and Remote Sensing, XVII ISPRS Congress, Washington DC. August 2-14, 1992, Commission VI, XXIX, part B: 375-381

Argialas, D. and Narasimhan, R. 1988a. TAX: A Prototype Expert System for Terrain Analysis. Journal of Aerospace Engineering, American Society of Civil Engineers, Vol. I, No. 3, July, pp. 151-170.

Argialas, D. and Narasimhan, R. 1988b. A Production System Model for Terrain Analysis Knowledge Representation. Microcomputers in Civil Engineering, Elsevier Science Pub. Co., Vol. 3, No. I, June, pp.-55-73.

Edwards, D. 1988. Research for reducing the labor intensive nature of high resolution terrain analysis feature extraction. Technical Paper, Annual Convention of American Society for Photogrammetry and Remote Sensing, Vol. 6, pp. 64-73, March 13-18, 1988, St. Louis, MI.

Fenneman, N. 1931. Physiography of the Western United States, McGraw-Hill Book Co., New York, NY.

Fenneman, N., 1938. Physiography of the Eastern United States, McGraw-Hill Book Co., New York, NY.

Hammond H., 1954. Small-Scale Continental Landform Maps: Annals of Assoc. of American Geographers. V44, P. 33-42

Harmon, P. & King, D. 1985. Expert systems: artificial intelligence in business. - Wiley & Sons, New York.

Hayes-Roth, F., Waterman, D. & Lenat, D. 1983. Building expert systems. - Addison-Wesley, Reading, MA.

Helms, C. 1986. The Sonoran Desert KC Publications

Hoffman, R. & R. Pike 1993. On the specification of the information available for the perception and description of the natural terrain. - In: J. Flash & P. Hancock (eds.): The ecology of human-machine interaction (volume 2). L. Erlbaum Assoc., Hillsdale, NJ.

Hoffman, R. 1985. What's a hill? An analysis of the meaning of generic topographic terms. - Final Report, Control No. DAAG-29-D-0100 Scientific Services Program, US Army Research Office, Alexandria, VA.

Hoffman, R. 1987. The problem of extracting the knowledge of experts from the perspective of experimental psychology. - The AI Magazine, 8, (2): 53-67.

Hunt B., 1973. Natural Regions of the United States and Canada, W.H. Freeman & Company, 714 p.

Hunt, C.B., 1975. Death Valley: Geology Ecology, Archaeology, University of California Press

IntelligenceWare 1986. Intelligence/Compiler User's Manual. - Los Angeles.

Jackson, P. 1986. Introduction to expert systems. - Addison-Wesley, Reading, MA.

Leighty, R. 1979. "Research for information extraction from aerial imagery." in: Remote Sensing Symposium, U.S. Army Corps of Engineers, Engineer Topographic Laboratory, Reston, VA.

Leighty, R., 1973. A Logical Approach Toward Terrain Pattern Recognition for Engineering Purposes, Ph.D. Dissertation, Department of Civil Engineering, The Ohio State University, Columbus, Ohio, 231 pp.

Lillelsand, T., & R. Kiefer 1979. Remote sensing and image processing. - John Wiley and Sons, New

York.

Lobeck, A. I932. Atlas of American Geology. The Geographical Press, Columbia University, New York, NY.

Lueder, D., 1959. Aerial Photographic Interpretation: Principles and Applications, McGraw-Hill, New York.

Mark, J. I976. Computer analysis of photo pattern elements. Photogrammetric Engineering and Remote Sensing, Vol. 42, No. 4, pp. 545-556.

Minsky, M., 1985. The Society of Mind. Simon and Schuster, N.Y., N.Y., pp. 339

Mintzer, O. & J. Messmore 1984. Terrain analysis procedural guide for surface configuration. - Technical Report ETL-0352, U.S. Army Corps of Engineer, Engineer Topographic Laboratory, Fort Belvoir, Virginia.

Mintzer, O. 1983. Engineering applications. - In: Colwell R. (ed.): Manual of Remote Sensing. American Society of Photogrammetry. - Falls Church, Virginia.

Mintzer, O. W. and J. A. Messmore, 1984: "Terrain Analysis Procedural Guide for Surface Configuration," Report No. ETL 0352, U. S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA.

Mintzer, O. W., 1988. Research in Terrain Knowledge Representation for Image Interpretation and Terrain Analysis, U.S. Army Symposium on Artificial Intelligence Research for Exploitation of Battlefield Environment, Nov 1-16, 1988 El Paso, Texas, pp. 277-293

Narasimhan, R. and Argialas, D. 1989. Computational Approaches for Handling Uncertainties in Terrain Analysis. Technical Paper, Annual Convention of American Society for Photogrammetry and Remote Sensing, Vol 3, pp. 302-310, April 2-7, 1989, Baltimore, Maryland.

Pandey S.N., 1987. Principles & Applications of Photogeology, John Wiley & Sons.

Peterson F., 1981. Landforms of the Basin & Range Province defined for soil survey, Technical Bulletin 28, Nevada Agricultural Experiment Station.

Rinker, J. and P. Corl, 1984. Air Photo Analysis, Photo Interpretation Logic, and Feature Extraction, Engineer Topographic Laboratories, U.S. Army Corps of Engineers, June, Report ETL-0329. Fort Belvoir, Virginia.

Short, N. and R. Blair, eds., 1986. Geomorphology from Space: A Global Overview of Regional Landforms, NASA SP-486, U.S. Government Printing Office, Washington, D.C.

Thompson and Turk 1993. Earth Science. Saunders College Pubs.

Townshend, J. (ed) 1981: Terrain Analysis and Remote Sensing. - London, Allen and Unwin, 272pp.

Way, D. 1978. Terrain Analysis. - McGraw-Hill. New York.